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# Comparison of Gastropod Assemblages from Natural and Phosphate Mine Lakes of Central Florida

by

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of the requirements for the degree of
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# ABSTRACT

Investigations were made examining the relationships between gastropod species richness and abundance across 20 phosphate and 20 natural lakes in Central Florida. In additional to lake category, age of phosphate lakes was used to determine if phosphate lakes ever approximate natural lakes. Additional physical, chemical, and biological parameters, including chlorophyll a, Ca, secchi, phosphorous, conductance, fish predation, and recreational lake use were investigated in order to determine if they affected gastropods with lake age. Comparisons were also made between gastropod species richness and average abundance and two groups of dominant vegetation categories: *Panicum*, a structurally complex macrophyte, and *Typha*, a less structurally complex macrophyte.

After phosphate mining operations are completed, Florida state regulations require the establishment of ecologically viable habitat (created lakes) which reflects the properties of regional natural lakes including vegetation structure, littoral zone, bank slope, and lake depth. The littoral zone is part of the mandated structure of the lake, and is of considerable importance to the uptake, storage, transformation and release of nutrients. Within the littoral zone, gastropods are a critical link in the food web with implications for the long term structure and function of a lake. They are known for their close associations with macrophytes and are common environmental indicators since they have limited mobility, high diversity, are well studied, are representative of their habitat type and have a widespread geographic range. They are also an important food sources for many predators in aquatic environments, include migratory waterfowl and game fish.

Gastropod species richness and abundance data were collected via standard net sweep methodology. Abundance was presented in catch per unit effort, therefore all abundance data were averages. Initial comparisons between gastropod species richness and average abundance yielded no significant differences between natural and phosphate lakes. However, when age was applied as a covariate, there was a significant difference between lake age as a continuous variable in species richness comparisons. Additionally, categorical comparisons between lakes older or younger than 30 years indicated significantly higher species richness and average abundance of gastropods in lakes phosphate lakes older than 30 years.

Physical and chemical properties of the lakes did not appear to influence gastropod populations between lakes of different ages. Fish predation interactions did not indicate any significant influence either. However, the presence of boat ramps did indicate a positive relationship between average gastropod abundance and species richness and recreational lake use.

Littoral zone macrophyte comparisons between dominant vegetation Typha and Panicum indicated a significantly positive relationship between gastropod species richness and average abundance in older phosphate lakes dominated by the more structurally complex Panicum macrophytes. Confidence in the Typha and Panicum results was confounded by lack of access to younger, Typha dominated, phosphate lakes. An increase in sample size for younger *Typha* lakes, with additional site access, may further support these findings.

# INTRODUCTION

## Phosphate Mining Regulations

Phosphate mining began in Florida during the late 1800's and currently disturbs 2,000-2,400 ha annually in central and northern Florida (Florida DEP, 2012). In the mining process, the overburden of 3 to 20 m of sand or clay is removed, drastically altering substrate structure, water tables, drainage patterns, and biological habitats (Florida Phosphate Council 1991, 1994). After mining operations are completed, mitigation is mandated to create ecologically viable habitat. Given their abundance throughout Florida, created lakes are a popular restoration option.

The State of Florida's promulgated land reclamation laws, beginning in 1975 (FDEP 2012, FIPR 2010), established regulations requiring created lakes to reflect the properties of regional natural lakes including vegetation structure, littoral zone, bank slope, and lake depth (Florida DEP, 2012).

Since the 1975 land reclamation laws, over 75,765 ha have been mined, 71% of which has been reclaimed (Bureau of Mining and Minerals Regulation, 2010). These laws, as specified by Chapter 62C-16 (FDEP 2012, FIPR 2010) outlined guidelines for establishing littoral zones in lakes constructed on phosphate mined lands including:

- Establish native wetland vegetation within 50% of the littoral zone within one year after initial appearance or active planting.
- At least 25% of the high-water surface area of a lake should consist of a zone of annual water fluctuation; at least 20% of the low-water surface area should consist of a zone between the annual low water line and 2 m below it.

- No reclaimed land slope, including the zone of fluctuation in the lake, should exceed 25%.

## Littoral Zone Properties

The littoral zone of a lake is of considerable importance to the uptake, storage, transformation and release of nutrients. The size of a littoral zone regulates the amount of nutrients loaded into a lake from terrestrial sources and the intensity of primary producers in open water. In addition to nutrient cycling, the littoral zone is an important refuge for young fish and aquatic invertebrates. Without the littoral zone, fish populations often are not be able to maintain themselves due to either lack of a predation refugium during developmental stages or diminished food sources as adults (Werner & Hall 1988, Diehl 1988, Savino & Stein 1989). The littoral zone acts as a buffer between nutrient loading from surrounding land use and the pelagic zone of the lake (Wetzel 2001).

Constructed lakes on phosphate lands quickly become eutrophic or hypertrophic (Mitraki dissertation). Rather than displaying a classical trophic surge before reducing productivity to a lower baseline condition, as commonly seen in reservoirs, lakes constructed on phosphate mined lands maintain high sustained trophic state throughout their history. This is a reflection of the abundance of phosphorus remaining in the terrestrial landscape long after mining practices have ceased. Cyanobacteria quickly colonize newly created lakes, with little chance of submersed macrophytes being established in the littoral zone due to shading (Mitraki and Crisman, unpublished data).

The main feature of a functioning littoral zone is the presence of macrophytes. Benthic invertebrate colonization in the littoral zone is more rapid than in the profundal zone (Mitraki 2012). Oxygen requirements of many taxa confine them to the shallow littoral zone. Mitraki

2012 compared benthic invertebrate communities of natural lakes and those built on phosphate mined lands and found no significant differences in invertebrate communities between the two lake types or abundance between littoral and profundal zones. Although vegetated littoral zones are mostly absent, total invertebrate taxa richness does not change significantly over time for either vegetated or bare bottom eutrophic phosphate lakes (Mitraki, 2012). Gastropods prefer highly vegetated littoral zones, and avoid sandy, inorganic sediments (Brown and Lodge, 1993). Gastropods may provide a clearer understanding of littoral zone success, due to their high affinity for macrophytes (Brown and Lodge, 1993).

## Gastropods as an Indicator Species

Gastropods are a critical link in the food web with implications for the long term structure and function of a lake. Gastropods are known for their close associations with macrophytes due to the macrophytes' increased foraging surface area, use as refugia from predation pressure, and use as egg laying surfaces (Brown and Lodge, 1993).  They are common environmental indicators since they have limited mobility, high diversity, are well studied, are representative of their habitat type and have a widespread geographic range. Gastropods are important food sources for many predators in aquatic environments. The Florida apple snail (*Pomacea paludosa*), is primary food for aquatic insects, crayfish, fishes, turtles (Snyder and Snyder 1969), alligators (Fogarty and Albury 1967), and birds such as white ibis, (Kushlan 1974), limpkins, boat-tailed grackles, and the endangered Everglades snail kite (Snyder and Snyder 1969). Juvenile *Pomacea* and more common, smaller snail species serve as important food sources for aquatic invertebrates, fish, and a variety of bird species. They are also known for their important and necessary role in transmission of parasites, such as trematodes.

Large game fish, such as bluegill and pumpkinseed sunfish, depend heavily on gastropods (Olson et al., 2003; Osenberg and Mittelbach, 1989). Migratory waterfowl, including greater and lesser scaup, mallards, and other dabbling ducks also regularly consume gastropods (Badzinski et al., 2006; Swanson et al., 1985; Wersal et al., 2005). Gastropods are unique in that, the function they perform in their environment is unique. They are by far the most dominant scraper feeders in lake food webs. If gastropods are not present in a littoral zone, the lake food web may be unstable. Without the role they perform as a primary consumer, nutrients from periphyton are not available for transmission to secondary and tertiary consumers. Secondary consumers that depend on gastropods as a primary food source may suffer population loss in the event of gastropod loss or absence from the littoral zone.

An example of how closely gastropod communities are associated with littoral macrophytes is Lake Apopka, Florida. As the system experienced rapid eutrophication, invertebrate communities increased with increasing macrophyte biomass. After the removal of the macrophyte biomass via a tropical hurricane, algal dominance was established and maintained, preventing reestablishment of macrophytes. Abundance of gastropods with known macrophyte associations increased with initial increases in eutrophy; however their abundance rapidly decreased when algal dominance was established (Crisman, Unpublished Study). *Hyalpyrgus aequicostatus*, a gastropod preferring surface substrate grazing, also disappeared entirely when anoxic conditions resulted from algal dominance (Crisman, Unpublished Study).

### Hypotheses

The current study addresses three hypotheses:

1. Natural lakes will have higher littoral zone gastropod richness and abundance than constructed phosphate lakes.

2. Gastropod species richness and abundance in created phosphate lakes will increase as a function of lake age, while chemical, physical, and biological parameters will not change with age of lake and therefore not control gastropods.
3. Constructed phosphate lakes dominated by high surface area vegetation (*Panicum*) will have higher Gastropod abundance than lakes dominated by low surface area vegetation (*Typha*).

# METHODS

## Study Site Descriptions

Phosphate lakes were adopted from previous benthic invertebrate studies by Mitraki 2012. These include sites in the Tenoroc and Clear Springs area. Additional sites for age comparisons were surveyed with assistance from the Florida DEP, including Lake Polk and Clear Springs. Natural lakes for comparison were established in the Lakeland and Winter Haven area of North-Central Florida. Forty lakes in total were sampled; 20 phosphate and 20 natural lakes. Exact location, age, and categorization of each lake sample were recorded (Table 1). Most lakes were sampled in close proximity to one another, in order to minimize geological and meteorological effects (Figure 1). All samples were taken between April and July 2013. Since their construction, the lakes sampled for comparisons are between 14 and 48 years old.

## Research Approach

### Hypothesis 1: Natural lakes will have higher littoral zone gastropod abundance than constructed phosphate lakes.

Comparisons to natural lake systems are the basis for regulations regarding constructed lake system success. The establishment of a functional littoral zone is the most important aspect of a lake. Assessment of the similarity of gastropod communities between natural and constructed phosphate systems is required as the first step in determining if the constructed phosphate system has adequately restored functionality to the lake.

To determine gastropod abundance for comparisons, a standard sampling method was used. Using a D-frame net with 0.3 m base length and 1.0 mm mesh size, ten 0.5 m sweeps were performed at each study lake. Each "sweep" consisted of placement of the net into the lake littoral zone. It was then dragged along the bank through vegetation, close to the bottom of the substrate, sampling the top layer of the substrate, if possible. Ten samples from each lake were determined to be appropriate for characterizing lake gastropod composition by a pilot study. Each sweep took place both in highly vegetated areas as well as bare areas of the lake's littoral zone. Presence or absence of emergent and submersed aquatic plants was used to quantify vegetation. There were ten samples in both bare and vegetated littoral zones, for a total of twenty samples from each lake. Gastropod species were collected from each sample, counted, and identified to species in lab (Burch 1989, Thompson, 2004). Based on availability of access, 40 lakes were sampled in total for all comparisons.

**Hypothesis 2: Gastropod species richness and abundance in created phosphate lakes will increase as a function of lake age, while chemical, physical, and biological parameters will not change with age of lake and therefore not control gastropods.**

Based on the slow colonization rate of gastropods, created lakes are expected to have slow initial recruitment. "Mucking" practices may inadvertently introduce some gastropod species. Since mucking is primarily employed encourage macrophyte establishment, the practice is not expected to be an effective means of gastropod introduction. Time is a key factor in the introduction of gastropods into a newly created system. Common introduction methods include flooding and bird transport, both of which vary with time and can be unpredictable. Therefore, as time passes, it is expected that, due to higher instances of introduction methods, gastropod abundance will increase in newly created lakes.

The total occurrence of gastropod species at each lake was recorded and compared to samples from other lakes. Comparisons were made between lakes of the same age class. Lakes constructed prior to 1975 were compared to lakes constructed after 1975 in an attempt to distinguish any difference in current gastropod abundance in lakes constructed both before and after the federal phosphate mining regulation changes. 20 lakes between the ages of 14 – 48 years old were sampled for comparisons.

**Hypothesis 3: Constructed phosphate lakes dominated by high surface area vegetation (*Panicum*) will have higher Gastropod abundance than lakes dominated by low surface area vegetation (*Typha*).**

Constructed lakes on phosphate mined lands are mostly eutrophic due to the high phosphorous content in the site geology. The abundance of available phosphorous will cause fast recruitment of littoral zone vegetation, assuming their recruitment is not prevented by algal dominance. High surface area littoral zone vegetation will allow for more complex grazing surfaces and refugia for gastropods.

Using the same sampling methodology from Hypothesis 1, constructed phosphate lakes with both *Panicum* and *Typha* presence were compared. Lakes constructed prior to 1975 were compared to lakes constructed after 1975 in an attempt to distinguish any difference in current gastropod abundance in lakes constructed both before and after the federal phosphate mining regulation changes. Using constructed lakes from older age classes should ensure that there has been adequate time for initial discovery of the constructed lakes, so that trends observed will be reflective of the habitat and not of discovery time.

**Statistical Analyses**

Comparisons were made for both gastropod species richness and abundance for all parameters. The average was taken for all sweep data collected on gastropod richness and abundance for each lake. Scatterplots were constructed using averages for the sweep data as well as physical and chemical parameters of the lakes. These parameters included: lake age, calcium levels, chlorophyll a, dissolved oxygen, alkalinity, total phosphorous, Secchi depth, and conductivity. The values for the chemical data were taken from the Polk County Water Atlas Database and Florida Lake Watch. Averages for all collected data for each lake were used. Each comparison was made with respect to age category for each phosphate lake. Additionally, all of the results for phosphate lakes were compared to the corresponding natural lake results.

Each lake was categorized by vegetation type, using data collected from field photos and Mitraki (2012). These plant type categories were plotted against gastropod species richness and abundance, separately, for both natural and phosphate lakes. T-tests were conducted for all comparisons to test for significance. General linear regression was also utilized in order to determine significant relationships between lake type and both chemical and physical parameters. Generalized linear regression was used to compare gastropod species richness and average gastropod abundance to lake type, lake age, and lake age categories. Fish creel data was graphed with both gastropod species richness and average gastropod abundance in order to determine predator-prey relationships.

# RESULTS AND DISCUSSION

## Species Richness

The species richness of each lake was determined (Table 2). Average richness for all phosphate lakes was 1.85; 2.58 for lakes older than 30 years, 0.77 for lakes younger than 30 years, and 2.70 for natural lakes. Initial comparisons between phosphate and natural lakes yielded no significant differences (Figure 3). In order to observe within group effects, phosphate lakes were organized by age. Generalized linear regression indicated a statistically significant difference between gastropod species richness and age as a continuous variable (Table 3). Initial figures indicated that there was a shift in observed values between lakes older and younger than 30 years (Figures 3 & 4). T –test comparisons between age groupings of older and younger than 30 years indicated a statistically significant difference between gastropod species richness ($p = 0.006$). The established age groupings were then compared using general linear regression. Because older phosphate lakes more closely corresponded to natural lakes, two analyses were performed: one including natural lakes in the older class and one excluding natural lakes. Both comparisons yielded significantly higher values for gastropod species richness in older phosphate lake groups (Table 3).

*Planorbella duryi* and *Gyraulus parvus* were not found in phosphate lakes. *Laevapex penninsularus* and *Pomacea insularum* were absent in lakes younger than 35 years, while *Pomacea paludosa* was found in only one lake younger than 35 years. *Planorbella scalaris* was less frequent and abundant in younger lakes, but was the most dominant species, found in 11 out of 20 lakes. *P. paludosa* (7/20), *Melannoides tuberculata* (6/20), and *L. penninsularis* (6/20) were the main subdominant species.

Pomacea were not highly represented in younger phosphate lakes. The most common pathway for introducing Pomacea is recreational boating or fishing. Considering younger phosphate lakes are relatively isolated and not open to the public, this could explain their reduced representation in younger lakes. The earliest time of colonization of phosphate lakes by individual snail species is not known; therefore, any species found in older phosphate lakes, but not ones older than 35, could be attributed to either time of colonization or lack of connectivity to other water bodies. As phosphate lakes become recreational sites, the odds of discovery increase greatly.

For natural lakes, *Physella gyrinna* (14/20) was the most dominant species. *P. insularum* (11/20), *M. tuburculata* (9/20), and *P. scalaris* (8/20) were subdominant species. *L. penninsularis* (1/20 lakes), *P. parvus* (2/20), and *P. paludosa* (2/20) were the least observed species.

The species comparisons between phosphate and natural lakes showed conflicting results. Natural lakes contained two species not present in any phosphate lakes, including *P. gyrina*, the most commonly found species in natural lakes. Additionally, *P. paludosa* and *L. peninsulae* were found in relatively few natural lakes, while commonly found in older phosphate lakes. Other species, such as *M. tuberculata* and *P. scalaris*, were found in high quantities in both older phosphate and natural lakes. Almost none of the observed gastropod species in younger phosphate lakes were similar to what was found in natural lakes.

**Abundance**

The total observed abundance for both lake categories was recorded and compared (Table 2). No significant differences were noted in the mean abundance of the natural versus phosphate lakes (Table 4). Using generalized linear regression techniques, there were no significant differences between average abundance and age as a continuous variable, and the T-test for average gastropod abundance was slightly below the 95% confidence interval (p=0.080). However, comparisons between phosphate age classes and average gastropod abundance demonstrated significantly higher values in the oldest age class (Table 3).

The species abundance (catch/sweep) of each lake was measured (Table 2). Average abundance for all phosphate lakes was 11.85, 3.40 for lakes older than 30 years, 0.24 for lakes younger than 30 years, and 2.14 for natural lakes. Most species were found in low quantities where they were present (< 10). In phosphate lakes, value for *M. tuberculata* were consistently high (>10). *P. insularum* was found in high quantities (> 40) at 1 old phosphate lake. *P. scalaris* was found in the highest quantity overall (150) at Tenoroc B. In natural lakes, Sawgrass displayed the highest abundance of species present. *M. tuberculata* were high (>10), reaching 90 individuals at Sawgrass. *P. insularum* was found in high quantities (> 40) at 2 lakes. Individual abundance values for any one lake or group were highly variable.

**Physical and Chemical Properties**

Averages of Ca, chlorophyll awa (ChlA), dissolved oxygen (DO), Secchi transparency, conductance, and total phosphorus (TP) were calculated from all available historical data. A MANOVA was used to compare all of the chemical and physical parameters between natural and phosphate lakes. After comparing the dispersion of the residual values, DO, conductance, Secchi level, and TP were log transformed. The MANOVA was performed again using the log values.

Ca (mg/l) ranged from 13 and 21 with a mean of 16.75 for natural lakes. For phosphate lakes, the range was between 13 and 25 with a mean of 18.65. There was no significant difference between phosphate and natural lake Ca values. During data collection, there was no visual evidence of shell erosion or thinning, indicating that all lakes provided adequate calcium for shell formation and maintenance.

Chl A (µg/l) ranged from 19 and 55 with a mean of 37.3 for natural lakes. For phosphate lakes the range was between 48 and 102 with a mean of 74.8. Chl A values were significantly higher in phosphate lakes (Table 4). The higher Chl A values indicate higher algal activity in phosphate lakes. The increased algal activity can be attributed to the higher TP.

Log conductance (mS/cm-1) ranged from 0.08 and 0.1 with a mean of 0.09 for natural lakes. For phosphate lakes the range was between 0.06 and 0.09 with a mean of 0.07. As with Ca, there was no significant difference between natural and phosphate lakes. Dissolved cations and anions were available in similar quantities in both lake categories.

Log DO (mg/l) ranged from 0.945 and 0.998 with a mean of 0.972 for natural lakes. For phosphate lakes the range was between 0.904 and 0.984 with a mean of 0.944. Though not significant, log DO values were actually higher in natural lakes. Gastropods depend on DO in varying capacities, depending on the species and respiration ability. The expectation that higher DO values would accompany higher Chl A values could be confounded by the amount of available periphyton present in phosphate lakes.

Log Secchi (cm) ranged from 1.7 and 2.2 with a mean of 1.8 for natural lakes. For phosphate lakes the range was between 1.6 and 2.1 with a mean of 1.8. Though not significant, Log Secchi values were higher in natural lakes. If the water column is clearer in natural lakes, as is indicated by higher Secchi values, it could be a more suitable environment for higher periphyton production.

Log TP (µg/l) ranged from 1.6 and 1.9 with a mean of 1.8 for natural lakes. For phosphate lakes the range was between 2.4 and 2.8 with a mean of 2.6. Log TP was significantly higher in phosphate lakes. Significantly higher TP values were expected, since the phosphate lakes are geologically rich in phosphorous.

## Respiration

Gastropod species can be separated by the presence/absence of gills and lungs. Two of the eight observed species relied solely on gills for respiration. The lakes were grouped by the presence of gilled species only, lunged species only, lunged and gilled species, or the complete absence of gastropods. The species richness of each respiration group was compared to DO levels in both phosphate and natural lakes.

Many of the collected gastropod species have adaptations for low oxygen conditions. *M. tuburculata*, though using gills for respiration, can survive low oxygen levels (Neck 1985). *P. gyrina* is able to withstand polluted waters and make use of surface oxygen using its mantle skirt (Harold and Guralwich 2010). *L. peninsulae* displays behavioral adaptations to low oxygen levels. It burrows into mud in winter and reduces oxygen consumption to minimal levels to survive anaerobic conditions (Branch 1980). Planorbid species are noted for their advanced hemoglobin structure, analogous to that of humans, indicating highly efficient use of oxygen (Herskowits and Hamilton 1990). Pomacea species syphon oxygen directly from the atmosphere and are entirely independent of DO (Burch 1989).

Phosphate lakes showed no dominant trends, but there was a slight peak in species richness around DO level of 9 mg/l (Figure 8). Seven lakes possessed no gastropods, five were comprised of only lunged species, one only had gilled species, and the remaining seven contained species with both gills and lungs. No one respiration type was clearly dominant.

The natural lakes had slightly increased gastropod species richness with increased DO (Figure 9). Additionally, there was only one lake with a complete absence of gastropods. Two lakes contained only lunged species. One lake contained only gilled species and the remaining sixteen lakes contained snails with both gills and lungs.

Average gastropod abundance of gilled and lunged species was compared in both phosphate and natural lakes. Phosphate lakes gastropod abundance showed a slight peak at DO levels of 9mg/l (Figure 10). Gilled and lunged gastropods were the only group with an average abundance greater than 2 snails/sweep. Natural lake comparisons showed a slight increase in average gastropod abundance with increased DO (Figure 11). Overall, lakes with both gilled and lunged species had higher average gastropod abundances.

### Fish Composition

A potential explanation for the significantly higher gastropod species richness and average abundance in older phosphate lakes might be predator-prey relationships. Some of the main predators on aquatic gastropods are bottom feeding fish. Creel data from the Tenoroc Fish Management area were used for the comparison of fish species to gastropod average abundance. Average fish abundance (catch/hr) was compared to average gastropod abundance (catch/sweep) for 10 phosphate lakes in the Tenoroc Fish Management area (Figure 5). The fish comparisons included both snail predators (catfish, black crappie, and bream) and large predatory fish (bass). All predators were present at each lake. Catfish were the most variable and also present in the highest quantities. Largemouth bass were present in consistently low numbers. There was no observable relationship between fish group abundance and gastropod abundance. Gastropod species richness and average abundance were compared to individual predator groups, separating out each gastropod predator and observing their abundance in each lake compared to average gastropod abundance and richness. These comparisons did not yield any observable trends or significant results.

### Recreational Lake Use

Recreational lake use was investigated as a potential vector of gastropod transportation. Since most phosphate lakes are isolated, the use of boats may transfer attached gastropods from one water body to another. Public boat ramp access was used as an indirect measurement of recreational lake use. All phosphate lakes were assessed for the presence of publicly accessible boat ramps. The presence or absence of boat ramps, obtained from the Florida Fish and Wildlife Conservation, was included as a covariate with lake age for both gastropod richness (Figure 12) and average abundance (Figure 13).

The majority of sampled lakes (16/20) possessed boat ramps. Regardless of the presence of boat ramps, gastropod species richness and average abundance was low in younger lakes. All lakes without boat ramps had very low average gastropod abundance values, including the oldest lake sampled. Species richness values were also low for lakes with no boat ramps.

### Macrophytes

Using both photos of each sampling site and field macrophyte collections by Mitraki (2012), each lake was categorized into three vegetation types: emergent, submersed, and free-floating plants. Phosphate lake littoral zone vegetation was often sparse, with disconnected patches of macrophyte growth. However, where macrophytes were present, *Typha* and *Panicum* were most dominant and often dense. Submersed vegetation was generally sparse, with a patchy distribution, when present. Free-floating vegetation was usually patchy and dead or wilted patches of hyacinth were observed, indicating chemical control. Natural and phosphate lakes were compared based on presence or absence of emergent, submersed, and free-floating plants types. All lakes were categorized based on the presence of these three plant groups.

Based on the observed vegetation, only three groups were created: Emergent only, Emergent and Free-Floating, and Emergent and Submersed. All phosphate and natural lakes were divided into these categories and compared with pair-wise T-tests. The T-test comparisons did not yield any significant differences between any of the plant categories at the 95% confidence interval. Gastropod species richness and average abundance values for Emergent, Emergent and Submersed, and Emergent and Free Floating categories did not differ between lakes, or between categories (Figure 2). The most structurally complex grouping (Emergent and Submersed) had the highest observed gastropod species richness and average abundance values, in both natural and phosphate lakes.

### ***Typha* and *Panicum* Dominance**

All sampled lakes had an emergent vegetation fringe and were classified as either *Panicum* or *Typha* dominated. Both *Typha* and *Panicum* grow very densely when dominant, but *Panicum* is more structurally complex than *Typha*. *Panicum* possesses many leaved extensions horizontally along a creeping stalk. The bulk of *Typha* biomass is in its root structure and it possesses a very tall, vertical stalk with very little, if any, horizontal extension. Increased complexity, due to vegetation structure, is related to higher amounts of periphyton recruitment (Messyasz & Kuczynska-Kippen 2005), refugia and aquatic invertebrate density (Rennie & Jackson 2005) due to increased surface area (Brown et al. 1988; Taniguchi et al. 2003).

Observations from Mitraki (2012) indicated that *Typha* established and became dominant in young (<10 years) and intermediate (< 20 years) lake age classes. *Panicum* was dominant in the oldest age class (> 25 years) and in some younger age classes. *Typha* recruits quickly and in high quantities with high amounts of available phosphorous. In systems with high phosphorous loading, open sloughs were converted to dense strands of *Typha domingensis* (Richardson et al. 2008; Davis 1991; Urban et al. 1993; Newman et al. 1998; King et al. 2004). However, *Typha* is eventually phased out by *Panicum* in older phosphate lakes, where high phosphate levels are constant. Since *Panicum* is a more structurally complex macrophyte than *Typha*, it provides greater surface area for refugia and periphyton recruitment. The grazing efficiency of gastropods is dependent on gastropod size and surface area of grazing substrate (Cattaneo and Kalff 1986). *Panicum* dominance in older phosphate lakes may be responsible for the higher gastropod species richness and average abundance values found in older lakes.

Based on observations and classifications from Mitraki (2012), each phosphate lake was classified as either *Typha* or *Panicum* dominated, then gastropod species richness was compared to lake age (Figure 6). The *Panicum* phosphate lakes consistently displayed equal or higher species richness than *Typha* lakes. The highest species richness values were in the older *Panicum* phosphate lakes. The significance of these relationships is unclear since, due to access limitations, only four *Typha* lakes were sampled.

Dominant emergent vegetation type was also used to compare average gastropod abundance to phosphate lake age (Figure 7). Gastropod abundance peaked in *Panicum* lakes between 1970 and 1975. Abundance also increased with increased lake age. *Typha* lakes did not display abundance values higher than 5 snails/sweep. Once again, significance of these relationships is unclear since, due to access limitations, only four *Typha* lakes were sampled.

# CONCLUSIONS

The first hypothesis, which stated natural lakes will have higher littoral zone gastropod richness and abundance than constructed phosphate lakes, was rejected. There was no statistically significant difference between gastropod species richness or average abundance between phosphate and natural lakes.

The second hypothesis, which stated, gastropod species richness and abundance in created phosphate lakes will increase as a function of lake age, was supported. As phosphate lakes age, gastropod species richness and average abundance increase. Gastropod species richness and average abundance values of old phosphate lakes (>30 years) ultimately resemble natural lakes. Among all tested parameters, the single greatest factor in gastropod species richness and average abundance was lake age. The difference in species richness in phosphate and natural lakes was not significant until age was introduced as a covariate, at which point significance was apparent with age, both continuously and categorically. Old phosphate and natural lake gastropod species richness was significantly higher than in young phosphate lakes. There was no significant difference in species richness between old phosphate and natural lakes. Species composition within lake categories showed differences between young phosphate lakes and both old phosphate and natural lakes. Natural and old phosphate lake species compositions were similar, though not identical. Comparisons between average gastropod abundance only yielded significant results when compared categorically. Young phosphate lake average gastropod abundance is significantly lower than old phosphate and natural lakes.

The physical, chemical, and biological variables that were explored as alternative explanations of observed age trends were not supported, except for recreational use. Chemical differences between phosphate and natural lakes were largely insignificant and not outside expected trends. Additional investigations into species composition by breathing type, for both natural and phosphate lakes, indicated gastropods that do not depend on DO were more abundant. Predator relationships yielded no explanation for differences between phosphate and natural lake gastropod species richness or average abundance. Gastropod species richness and average abundance was not significantly different based on observed fish predation. Additional lakes could be sampled in future studies, as well as population affects caused by migratory waterfowl. Recreational use, observed by the presence of publicly available boat ramps, did show a relationship between gastropod species richness and average abundance. Boat use in lakes allows for the introduction or transfer of gastropod species. As a result, phosphate lakes with no boat ramps had much lower average gastropod abundance values, regardless of age. Gastropod species richness was also lower in lakes with no boat ramps.

Hypothesis three, which stated, constructed phosphate lakes dominated by high surface area vegetation (*Panicum*) will have higher Gastropod abundance than lakes dominated by low surface area vegetation (*Typha*), was tentatively supported. The vegetation type categorizations did not yield any significant trends. However, the more structurally complex category (Emergent and Submersed) did have the highest values for both gastropod species richness and average abundance in natural and phosphate lakes. There was a significant difference between *Typha* and *Panicum* vegetation categories for both gastropod species richness and average abundance. The increased gastropod species richness and average abundance is attributed to the higher structural complexity of these lakes compared to lakes dominated by *Typha*. However, due to access restrictions, there were not enough samples in the *Typha* category for adequate confidence in the results. Based on the observations from Mitraki (2012), it is anticipated that younger phosphate lakes will be *Typha* dominated. An increase in sample size for *Typha* lakes may further support these findings. Investigation into the composition of the vegetation, particularly in lakes less than 10 years old, could be performed with additional site access.

# TABLES AND FIGURES

Table 1: All lakes sampled during the study period. 20 phosphate and 20 natural lakes were sampled. All samples took place between April and July 2013.

| Map Label | Lake Name | Classification | Age | Date Sampled | Latitude | Longitude |
|---|---|---|---|---|---|---|
| A | Polk | Phosphate | 14 | 13-May | 27° 54' N | 81° 46' W |
| B | Anne2 | Phosphate | 17 | 13-May | 27° 53' N | 81° 45' W |
| C | Lake Somerset | Phosphate | 23 | 11-Jul | 28° 00' N | 81° 55' W |
| D | CSPC2 | Phosphate | 26 | 13-May | 27° 50' N | 81° 48' W |
| E | Hardee 1 | Phosphate | 28 | 10-Jun | 27° 37' N | 81° 57' W |
| F | Hardee 2 | Phosphate | 28 | 10-Jun | 27° 37' N | 81° 58' W |
| G | Hardee 3 | Phosphate | 28 | 10-Jun | 27° 38' N | 81° 58' W |
| H | Hardee 4 | Phosphate | 28 | 10-Jun | 27° 38' N | 81° 58' W |
| I | Lake John | Phosphate | 34 | 11-Jul | 28° 00' N | 81° 56' W |
| J | Tenorac B | Phosphate | 36 | 23-May | 28° 05' N | 81° 54' W |
| K | Tenorac G | Phosphate | 38 | 22-May | 28° 05' N | 81° 53' W |
| L | Lake F | Phosphate | 38 | 22-May | 28° 05' N | 81° 53' W |
| M | Hydrilla | Phosphate | 42 | 23-May | 28° 04' N | 81° 54' W |
| N | Picnic | Phosphate | 42 | 23-May | 28° 06' N | 81° 51' W |
| O | Horseshoe | Phosphate | 42 | 23-May | 28° 06' N | 81° 55' W |
| P | Halfmoon | Phosphate | 42 | 23-May | 28° 05' N | 81° 56' W |
| Q | Butterfly | Phosphate | 42 | 23-May | 28° 06' N | 81° 55' W |
| R | Tenorac 5 | Phosphate | 42 | 23-May | 28° 05' N | 81° 51' W |
| S | Tenorac 4 | Phosphate | 42 | 22-May | 28° 05' N | 81° 51' W |
| T | Homeland | Phosphate | 48 | 15-May | 27° 48' N | 81° 47' W |
| U | Belulah | Natural | NA | 15-Jun | 28° 04' N | 81° 58' W |
| V | Hunter | Natural | NA | 8-Jul | 28° 01' N | 81° 57' W |
| W | Wire | Natural | NA | 15-Jun | 28° 02' N | 81° 57' W |
| X | Hollingsworth | Natural | NA | 8-Jul | 28° 01' N | 81° 56' W |
| Y | Bonny | Natural | NA | 8-Jul | 28° 02' N | 81° 55' W |
| Z | Eagle Lake | Natural | NA | 17-Jul | 27° 59' N | 81° 45' W |
| AA | Lake Eloise | Natural | NA | 17-Jul | 27° 59' N | 81° 41' W |
| AB | Newnan Lake | Natural | NA | 30-Apr | 29° 38' N | 82° 13' W |
| AC | Crescent Lake | Natural | NA | 15-Apr | 27° 47' N | 82° 38' W |
| AD | Sawgrass | Natural | NA | 1-Apr | 27° 50' N | 82° 40' W |
| AE | Van | Natural | NA | 23-Jul | 28° 06' N | 81° 45' W |
| AF | Roy | Natural | NA | 31-Jul | 28° 00' N | 81° 42' W |
| AG | Marianna | Natural | NA | 23-Jul | 28° 04' N | 81° 45' W |
| AH | Arianna | Natural | NA | 23-Jul | 28° 04' N | 81° 48' W |
| AI | Elbert | Natural | NA | 31-Jul | 28° 01' N | 81° 42' W |
| AJ | Mattie | Natural | NA | 23-Jul | 28° 08' N | 81° 46' W |
| AK | Shipp | Natural | NA | 31-Jul | 28° 00' N | 81° 44' W |
| AL | McLeod | Natural | NA | 31-Jul | 27° 58' N | 81° 45' W |
| AM | Parker | Natural | NA | 11-Jul | 28° 03' N | 81° 56' W |
| AN | Juliana | Natural | NA | 23-Jul | 28° 07' N | 81° 48' W |

Table 2: Gastropod species total observed abundance and richness organized by lake age and category. 20 phosphate and 20 natural lakes were sampled between April and July 2013.

| Category | Created | Name | Species Richness | Average Abundance | *Melanoides tuberculata* | *Physella gyrina* | *Laevapex peninsulas* | *Gyraulus parvus* | *Pomacea paludosa* | *Planorbella scalaris* | *Planorbella duryi* | *Pomacea insularum* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Phosphate | 1965 | Homeland | 2 | 0.4 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 |
| Phosphate | 1971 | Butterfly | 4 | 1.2 | 0 | 0 | 5 | 0 | 1 | 3 | 0 | 3 |
| Phosphate | 1971 | Halfmoon | 5 | 6.1 | 36 | 0 | 2 | 0 | 8 | 14 | 0 | 1 |
| Phosphate | 1971 | Horseshoe | 1 | 0.1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Phosphate | 1971 | Hydrilla | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Phosphate | 1971 | Picnic | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Phosphate | 1971 | Tenorac 4 | 4 | 1.1 | 1 | 0 | 2 | 0 | 1 | 7 | 0 | 0 |
| Phosphate | 1971 | Tenorac 5 | 2 | 0.2 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| Phosphate | 1975 | Tenorac F | 5 | 10.6 | 5 | 0 | 1 | 0 | 3 | 6 | 0 | 91 |
| Phosphate | 1975 | Tenorac G | 4 | 3.8 | 2 | 0 | 0 | 0 | 5 | 22 | 0 | 9 |
| Phosphate | 1977 | Tenorac B | 4 | 17.3 | 1 | 19 | 3 | 0 | 0 | 150 | 0 | 0 |
| Phosphate | 1979 | Lake John | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Phosphate | 1985 | Hardee 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Phosphate | 1985 | Hardee 2 | 1 | 0.3 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| Phosphate | 1985 | Hardee 3 | 2 | 0.5 | 0 | 1 | 0 | 0 | 0 | 4 | 0 | 0 |
| Phosphate | 1985 | Hardee 4 | 2 | 0.2 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| Phosphate | 1987 | CSPC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Phosphate | 1990 | Lake Somerset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Phosphate | 1996 | Anne2 | 1 | 0.9 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Phosphate | 1999 | Polk | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Natural | NA | Arianna | 1 | 0.1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Natural | NA | Belulah | 2 | 1 | 0 | 5 | 0 | 0 | 5 | 0 | 0 | 0 |
| Natural | NA | Bonny | 5 | 6.7 | 23 | 6 | 0 | 0 | 0 | 22 | 7 | 9 |
| Natural | NA | Crescent | 3 | 2.1 | 19 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Natural | NA | Eagle | 2 | 0.3 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 0 |
| Natural | NA | Elbert | 2 | 0.3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Natural | NA | Eloise | 3 | 1.5 | 0 | 8 | 0 | 0 | 0 | 3 | 0 | 4 |
| Natural | NA | Hollingsworth | 1 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Natural | NA | Hunter | 3 | 1.2 | 0 | 2 | 0 | 0 | 4 | 6 | 0 | 0 |
| Natural | NA | Juliana | 3 | 4.3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 41 |
| Natural | NA | Marianna | 2 | 0.2 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Natural | NA | Mattie | 1 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Natural | NA | McLeod | 3 | 2.1 | 15 | 1 | 0 | 0 | 0 | 0 | 0 | 5 |
| Natural | NA | Newnan | 4 | 7.7 | 0 | 15 | 0 | 0 | 0 | 5 | 8 | 49 |
| Natural | NA | Parker | 3 | 0.9 | 0 | 5 | 0 | 0 | 0 | 0 | 3 | 1 |
| Natural | NA | Roy | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Natural | NA | Sawgrass | 6 | 24.2 | 90 | 68 | 6 | 12 | 0 | 28 | 38 | 0 |
| Natural | NA | Shipp | 3 | 0.6 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Natural | NA | Van | 2 | 0.2 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| Natural | NA | Wire | 2 | 0.2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

Table 3: Generalized linear regression of gastropod species richness and average abundance compared to categorical and continuous variables. Lake categories consisted of phosphate and natural lakes. 20 phosphate and 20 natural lakes were compared. Age groups consisted of lakes < 30 and > 30 years of age. Comparisons included both phosphate and natural lake values except where otherwise noted. In age group comparisons with natural lakes, their values were included with the >30 age class. Red values indicate a $p < 0.05$.

| Gastropod Species Richness | | | | | |
|---|---|---|---|---|---|
| | | Degr. of Freedom | Log- Likelihd | Chi- Square | p |
| | LakeCategory | 1 | -57.7637 | 1.937720 | 0.163916 |
| | Age | 1 | -34.8465 | 5.762693 | 0.016370 |
| w/Natural | AgeGroup | 1 | -62.5081 | 16.73560 | 0.000043 |
| w/o Natural | AgeGroup | 1 | -36.9001 | 11.51624 | 0.000690 |
| Gastropod Average Abundance | | | | | |
| | | Degr. of Freedom | Log- Likelihd | Chi- Square | p |
| | LakeCategory | 1 | -132.538 | 0.128905 | 0.719570 |
| | Age | 1 | -58.1055 | 0.704419 | 0.401303 |
| w/Natural | AgeGroup | 1 | -132.880 | 4.502080 | 0.033854 |
| w/o Natural | AgeGroup | 1 | -59.0754 | 7.368560 | 0.006637 |

Table 4: MANOVA results of the chemical and physical properties of 40 lakes by lake category. Physical data collected over a period between 1973 and 2014. Values for Chl a and logTP were significantly higher in phosphate lakes than natural lakes. Other chemical and physical parameters did not differ significantly. Red values indicate a $p < 0.05$.

| | Category | Error | Total | | Category | Error | Total |
|---|---|---|---|---|---|---|---|
| Degr. of Freedom | 1 | 21 | 22 | Degr. of Freedom | 1 | 21 | 22 |
| Ca SS | 17.227 | 1248.284 | 1265.511 | logCond SS | 0.001281 | 0.007812 | 0.009093 |
| Ca MS | 17.227 | 59.442 | | logCond MS | 0.001281 | 0.000372 | |
| Ca F | 0.2898 | | | logCond F | 3.4445 | | |
| Ca p | 0.596002 | | | logCond p | 0.077552 | | |
| Chl a SS | 6844.63 | 25561.23 | 32405.86 | logDO SS | 0.00388 | 0.05303 | 0.05691 |
| Chl a MS | 6844.63 | 1217.20 | | logDO MS | 0.00388 | 0.00253 | |
| Chl a F | 5.62326 | | | logDO F | 1.537 | | |
| Chl a p | 0.027364 | | | logDO p | 0.228780 | | |
| logSecchi SS | 0.00695 | 2.41332 | 2.42027 | logTP SS | 3.26563 | 1.88482 | 5.15045 |
| logSecchi MS | 0.00695 | 0.11492 | | logTP MS | 3.26563 | 0.08975 | |
| logSecchi F | 0.0605 | | | logTP F | 36.384 | | |
| logSecchi p | 0.808115 | | | logTP p | 0.000005 | | |

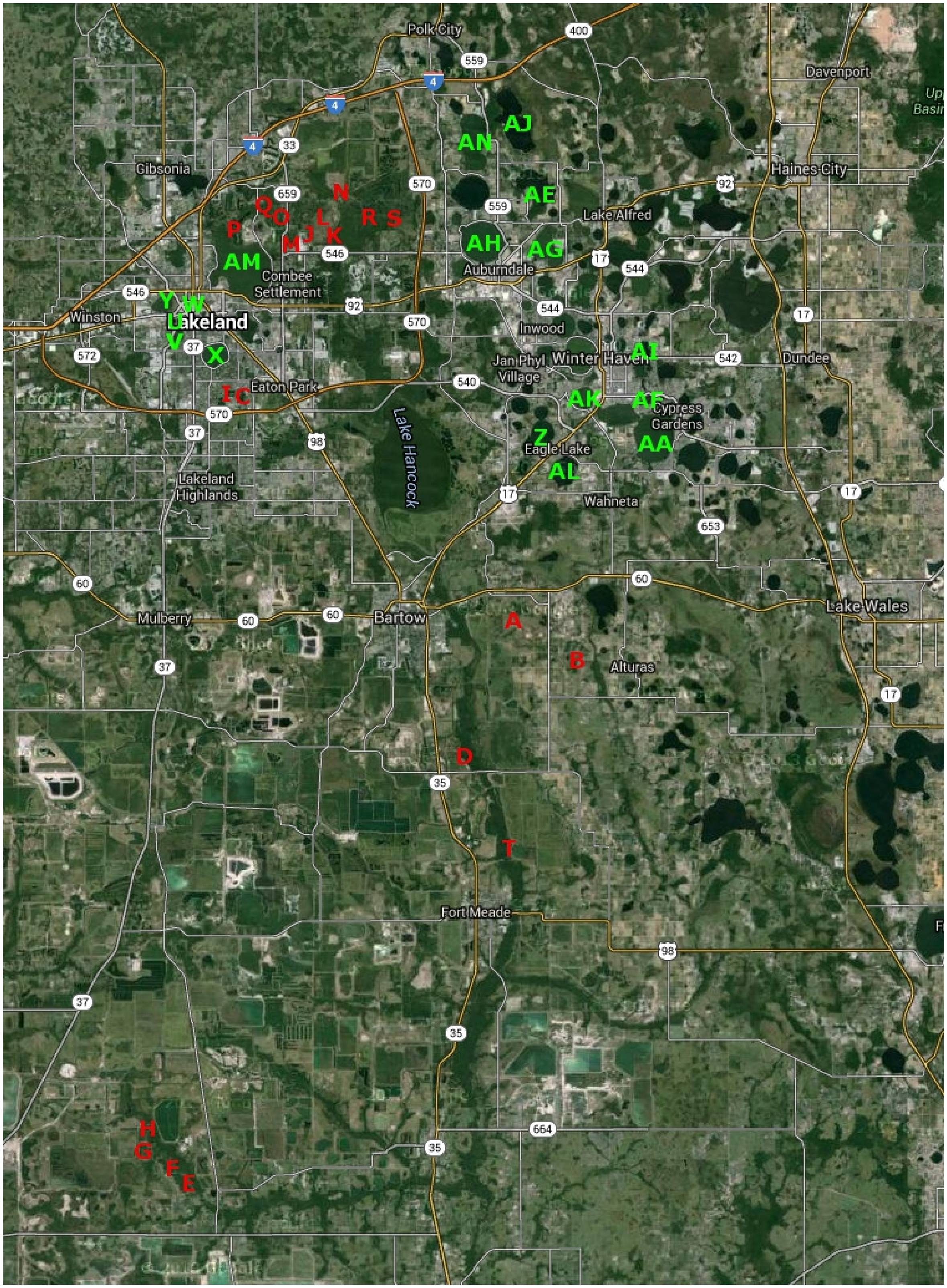

Figure 1: Map of all study site locations. Labels correspond to column 1 of Table 1. The majority of samples were taken from the Lakeland and Winter Haven regions of central Florida. Sawgrass, Newnan, and Crescent lakes are not shown.

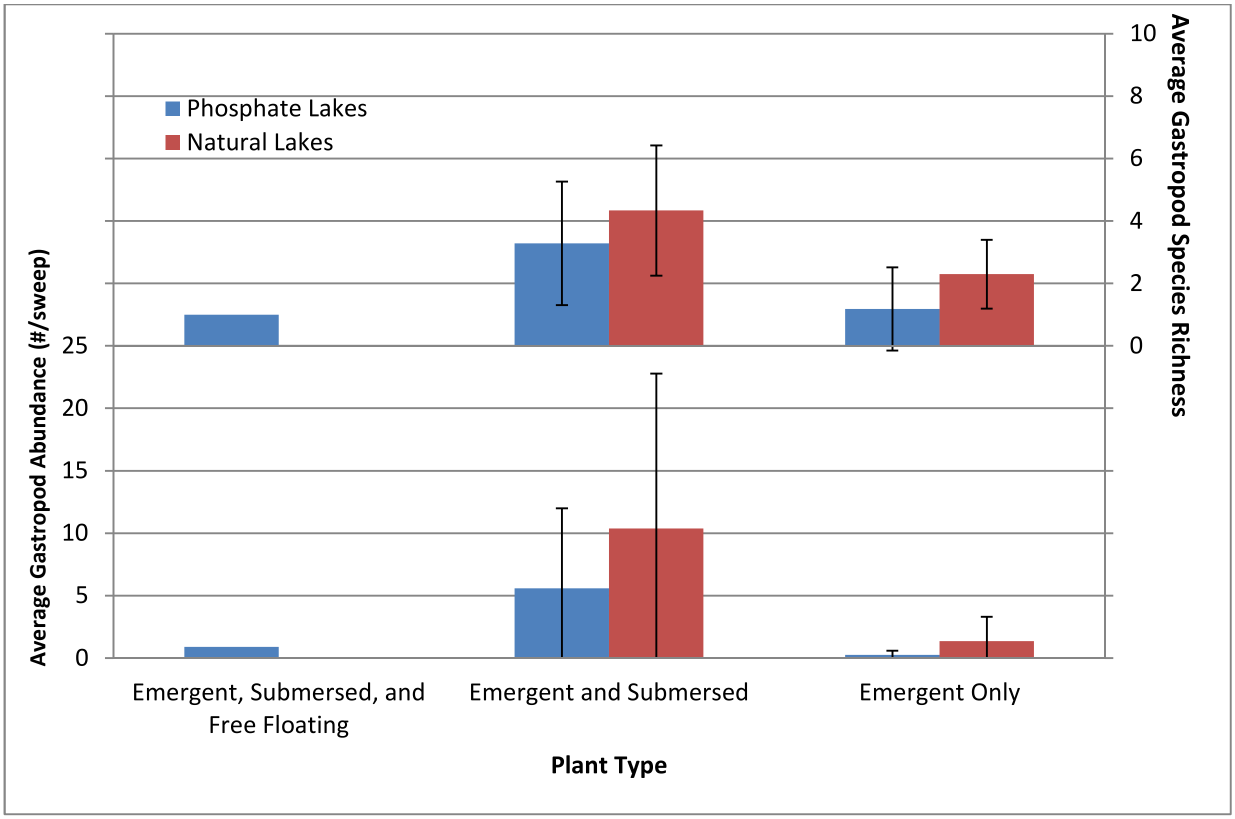

Figure 2: Average gastropod species richness and abundance compared to plant type categories of 20 natural and 20 phosphate lakes. Error bars represent one standard deviation. Phosphate lakes sampled contained 11 lakes in the emergent, 4 lakes in emergent and free-floating, and 5 lakes in the emergent and submersed categories. Natural lakes sampled contained 17 lakes in the emergent, 0 lakes in emergent and free-floating, and 3 lakes in the emergent and submersed categories. Mean data values did not differ significantly (P<0.05) for either species richness or abundance values between any of the plant categories.

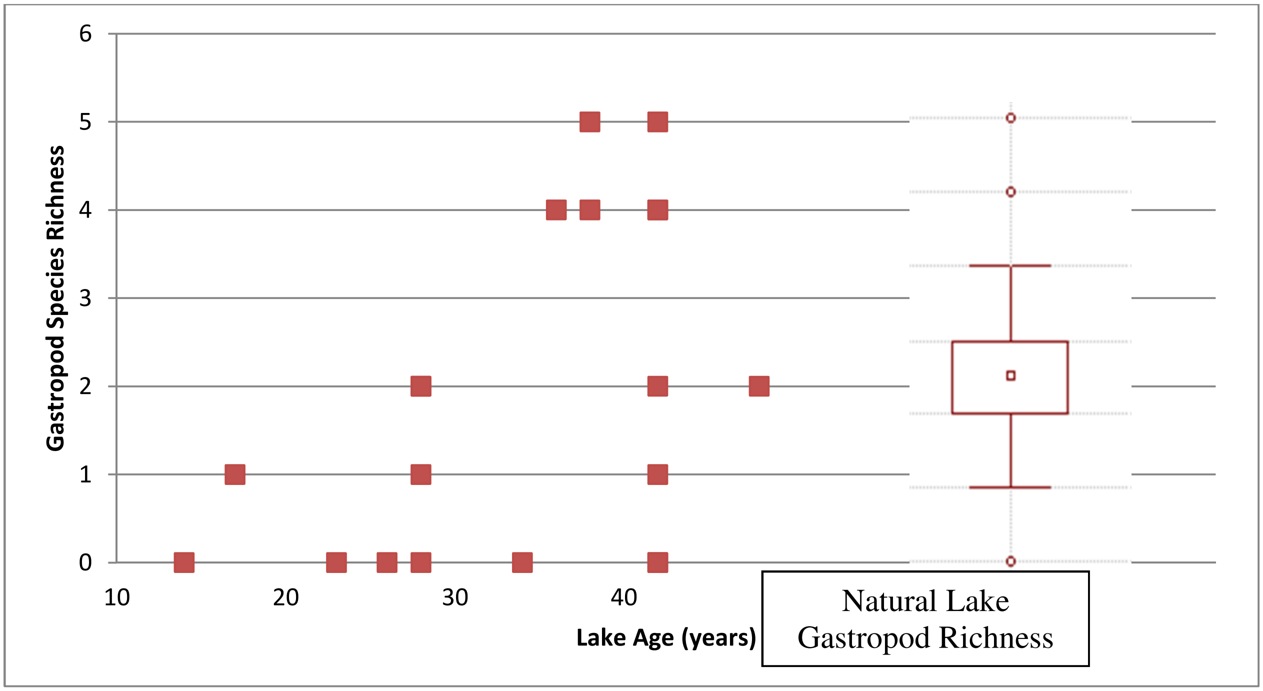

Figure 3: Gastropod species richness compared to the age of 20 phosphate lakes. Natural lake data of 20 lakes presented to the right for comparison, as age comparisons are not valid. Mean data values did not differ significantly (P<0.05) for species richness values between natural and phosphate lakes.

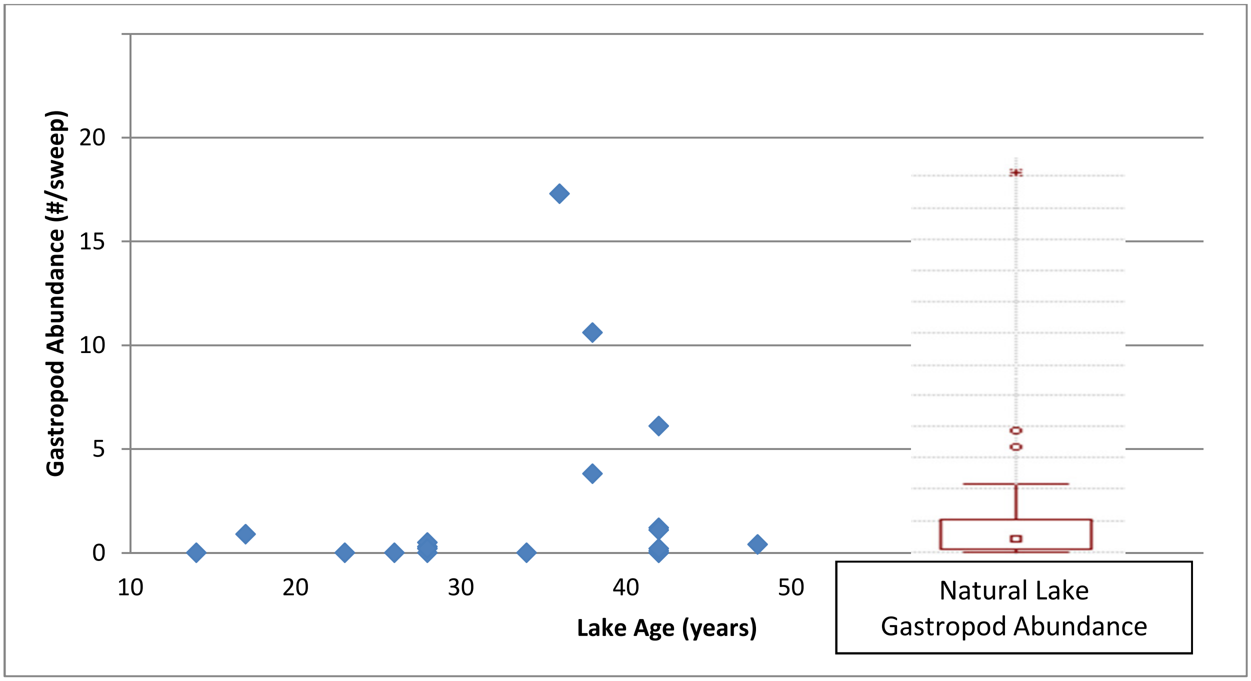

Figure 4: Gastropod average abundance compared to the age of 20 phosphate lakes. Natural lake data of 20 lakes presented to the right for comparison, as age comparisons are not valid. Mean data values did not differ significantly (P<0.05) for abundance values between natural and phosphate lakes.

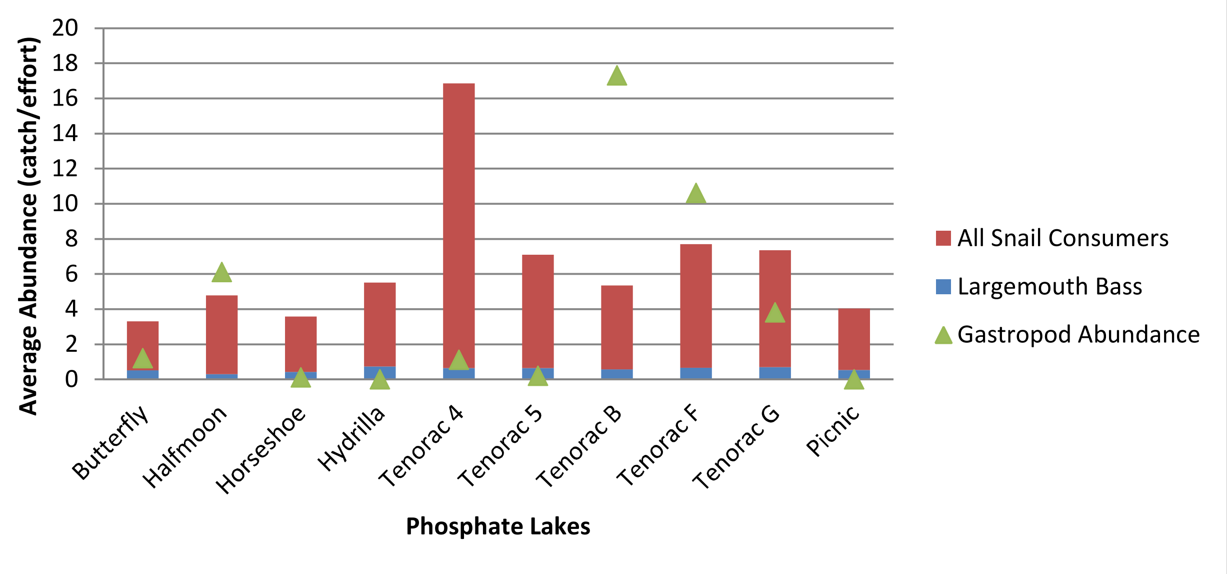

Figure 5: Average abundance of largemouth bass (catch/hr), combined snail consumers (catch/hr), and gastropods (#/sweep). Samples were collected for 10 phosphate lakes in the Tenoroc Fish Management Area. Fish creel data was compiled over a 13 year period. Standard deviations were calculated for largemouth bass (0.14), all snail consumers (3.89), and gastropods (5.80).

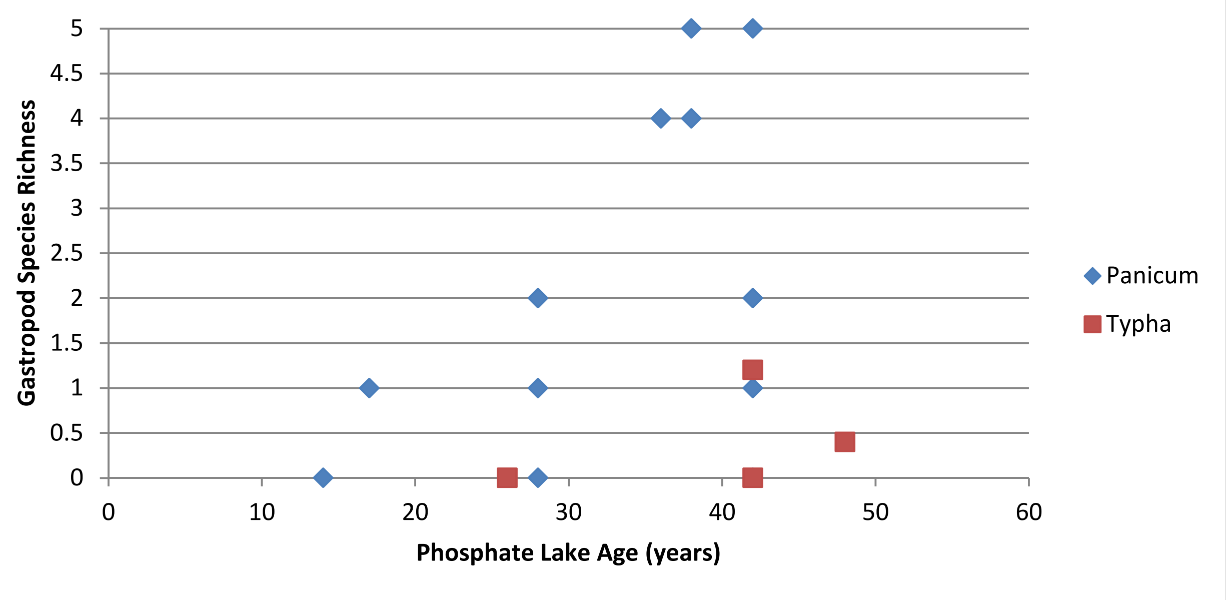

Figure 6: Gastropod species richness compared to the age and dominant emergent vegetation type of 20 phosphate lakes. Lakes were classified based on dominant vegetation in sampling area. Additional *Typha* dominated lakes were unavailable for sampling.

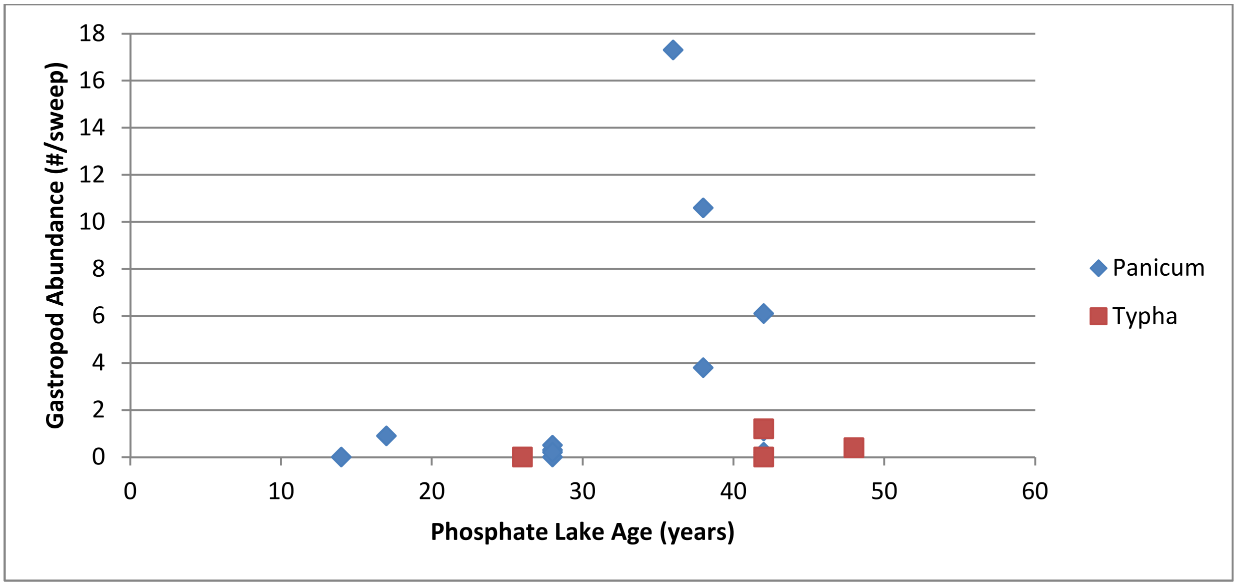

Figure 7: Average gastropod abundance compared to the age and dominant emergent vegetation type of 20 phosphate lakes. Lakes were classified based on dominant vegetation in sampling area. Additional *Typha* dominated lakes were unavailable for sampling.

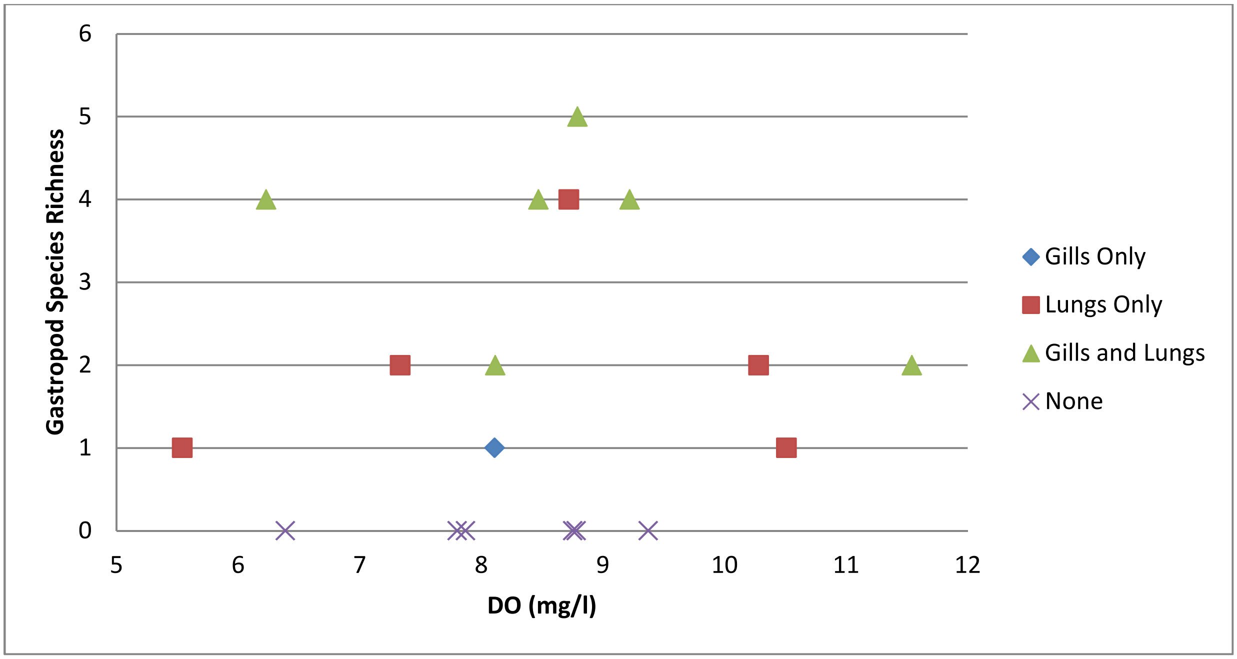

Figure 8: Gastropod species richness sorted by gastropod respiration type compared to average dissolved oxygen (mg/l) values for 17 phosphate lakes. DO values collected over a period between 1973 and 2014.

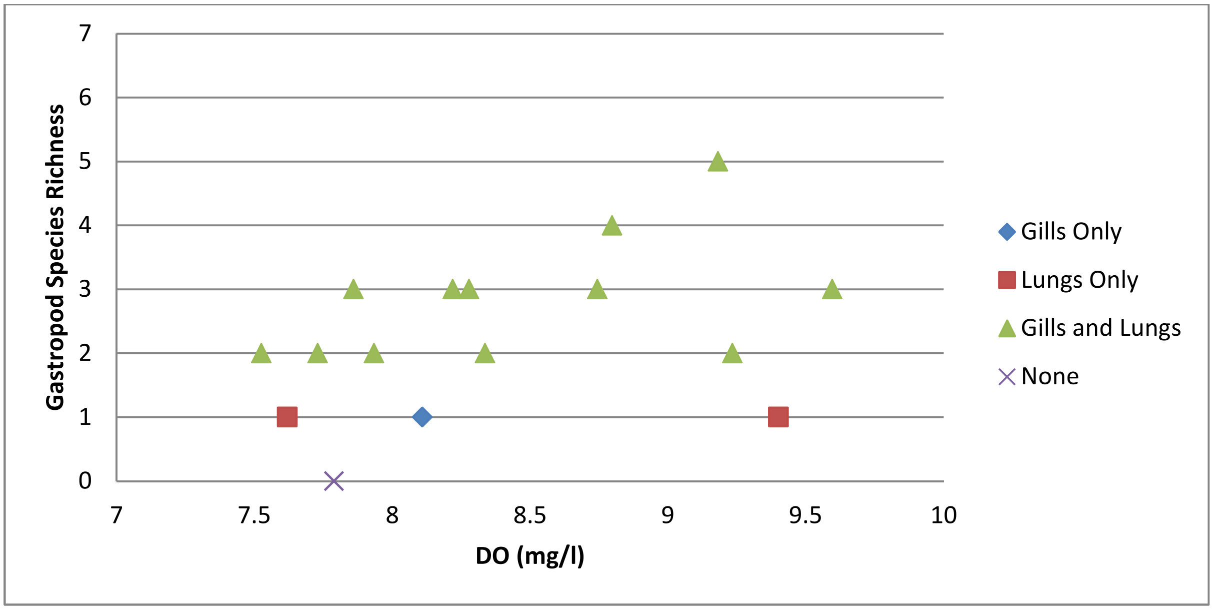

Figure 9: Gastropod species richness sorted by gastropod respiration type compared to average dissolved oxygen (mg/l) values for 16 natural lakes. DO values collected over a period between 1973 and 2014.

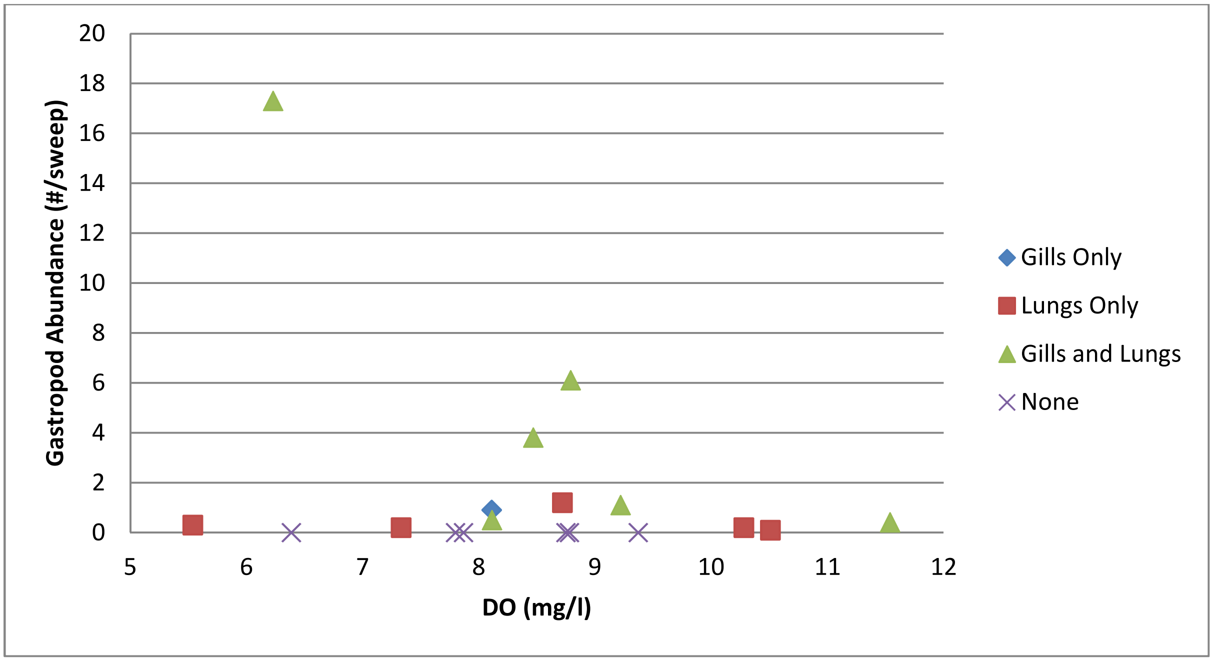

Figure 10: Average gastropod abundance sorted by gastropod respiration type compared to average dissolved oxygen (mg/l) values for 17 phosphate lakes. DO values collected over a period between 1973 and 2014.

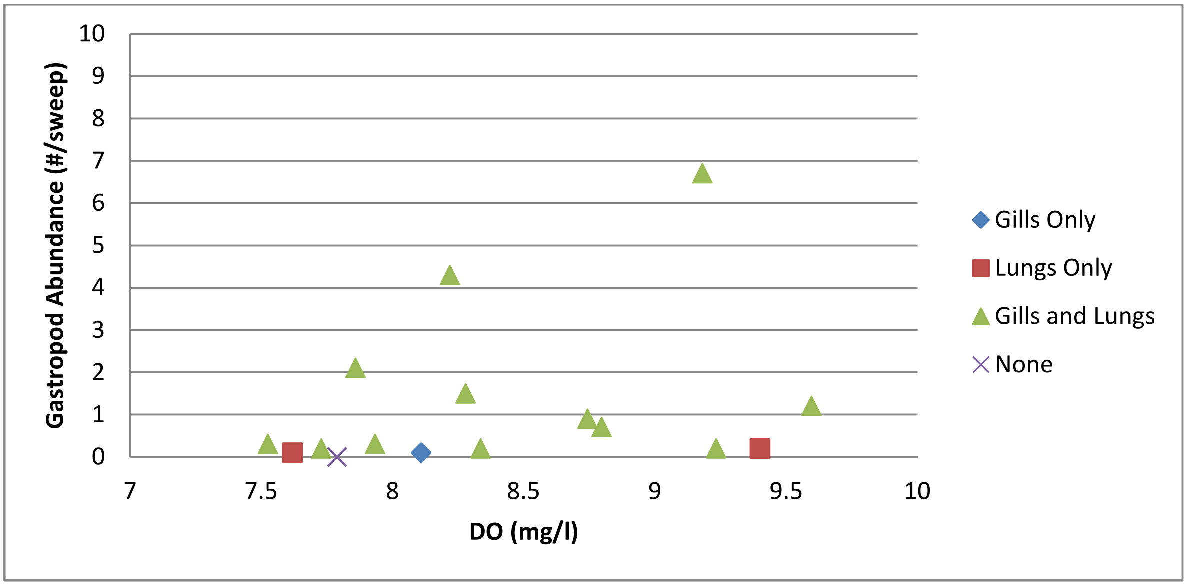

Figure 11: Average gastropod abundance sorted by gastropod respiration type compared to average dissolved oxygen (mg/l) values for 16 natural lakes. DO values collected over a period between 1973 and 2014.

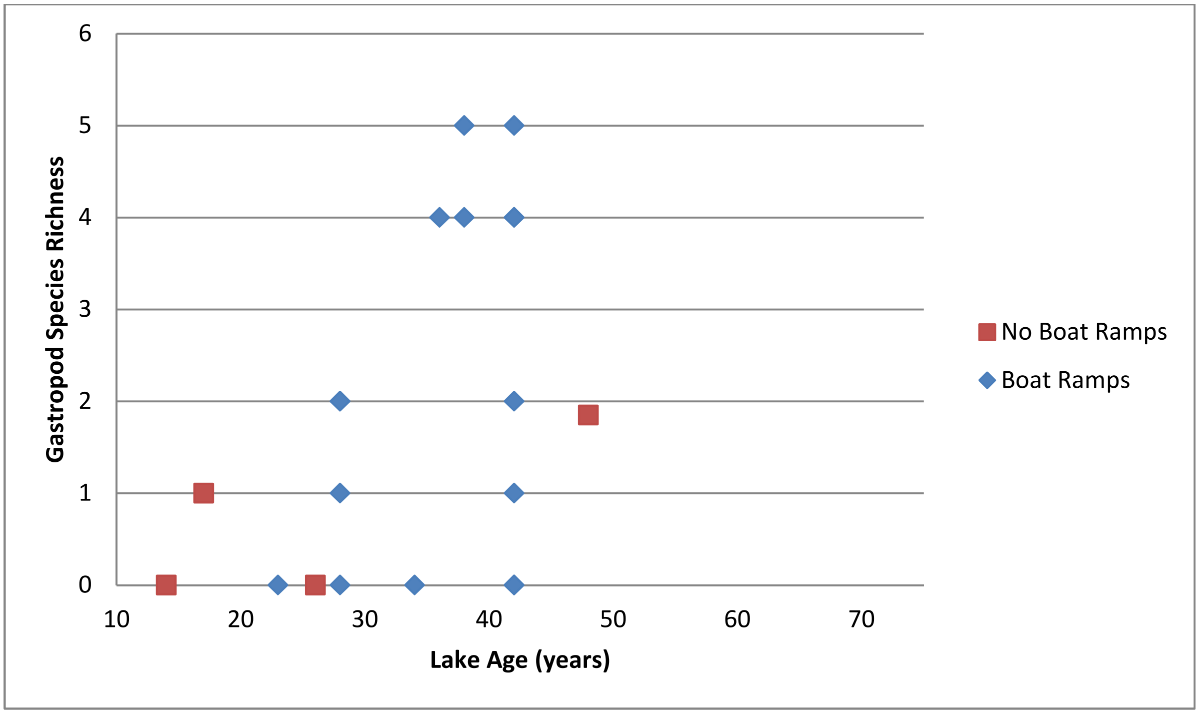

Figure 12: Gastropod species richness of 20 phosphate lakes compared to lake age (years). Lakes were categorized by the presence or absence of boat ramps.

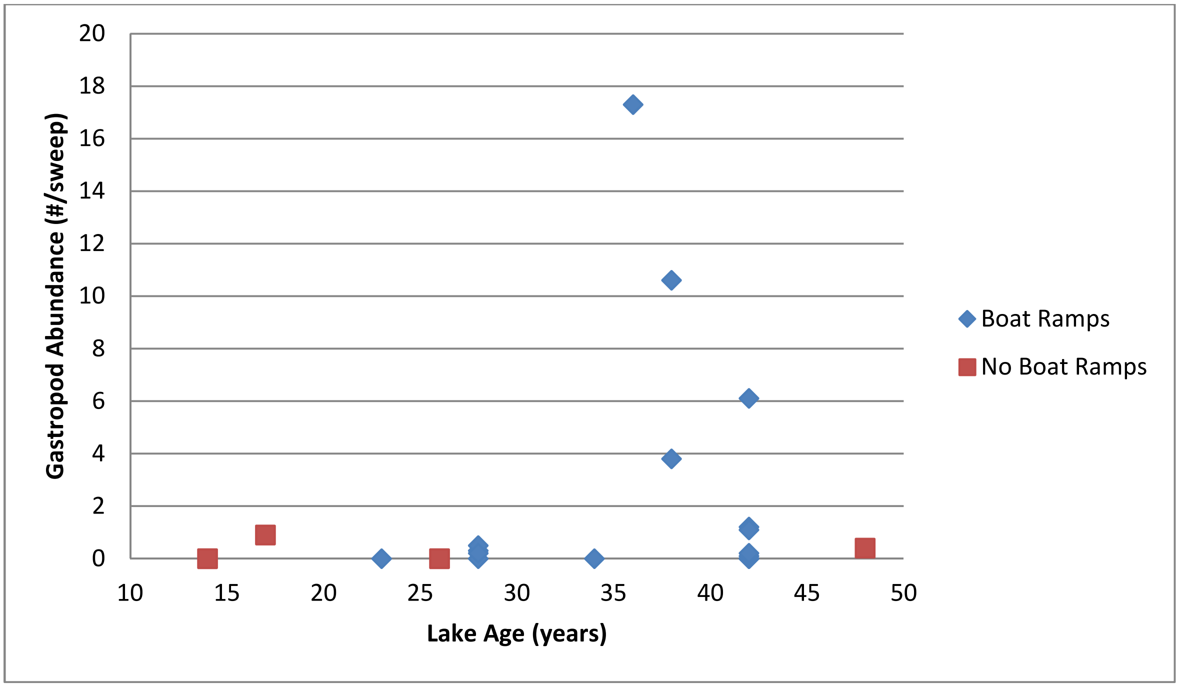

Figure 13: Average gastropod abundance of 20 phosphate lakes compared to lake age (years). Lakes were categorized by the presence or absence of boat ramps.

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